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The Potential for Mitigation of Gun Blast Noise Through Sheltering of the Source

by

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Community reaction to noise from guns of various sizes is a continuing problem for Army training facilities. While the higher-frequency components of gun noise are substantially attenuated by the atmosphere, the low frequency components are often strong enough to cause annoyance or alarm in the surrounding community. It is desirable for training range managers to mitigate noise as much as possible at the source to avoid violating local noise regulations and risking the loss of training capacity.

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FOREWORD

This research was conducted for the Office of the Chief of Engineers (OCE) under Project 62720A896, "Environmental Quality Technology"; Task Area NN; Work Unit TU1, "Noise Mitigation and Noise Impact Management Practices." The OCE technical monitor is LTC Hans Graven, ENVR-E.

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THE POTENTIAL FOR MITIGATION OF GUN BLAST NOISE THROUGH SHELTERING OF THE SOURCE

1 INTRODUCTION

Background

Community reaction to noise from guns of various sizes is a continuing problem for Army training facilities. Cantonment areas and civilian housing may be located up to several kilometers away, so the higher-frequency noise components are substantially attenuated in the air. However, the low frequency components of blast noise may be heard or felt at levels sufficient to cause annoyance or alarm. In particular, low frequency noise can cause unpleasant rattling or shaking of structures.

It has been suggested that a community in a specific direction from a firing point could be shielded significantly from gun noise by a barrier or shelter erected in the immediate vicinity of the gun. Barriers for this purpose have been built at a number of sites, but it is not known whether the effectiveness of these structures has been quantified.

Objective

The objective of this research is to investigate the potential effectiveness of representative gun noise barriers built to shield nearby communities from excessive noise.

Approach

The problem is one of classical diffraction theory, solved in the temporal frequency domain. Mathematical analyses based on diffraction theory were performed on various sizes and configurations of noise barriers to determine their effectiveness in mitigating gun noise near the source. Analyses were performed on noise barrier configurations for both large gun blast noise (e.g., artillery, tanks) and rifle fire.

Scope

To expedite the analytical process, these mathematical analyses were performed on structural designs and noise sources with idealized properties that cannot practically be duplicated in the field. Experience with diffraction problems suggests that findings for the domelike structures analyzed are generally applicable to rectilinear structures whose general dimensions and proportions are similar.

Mode of Technology Transfer

This study supports USACERL research into the mitigation of small arms noise, the product of which will be demonstrated through the Facilities Engineering Applications Program (FEAP). Additionally, the Army Environmental Hygiene Agency (AEHA) will be able to apply the findings of this study where applicable in its noise mitigation activities.

2 SHELTERING THE SOURCE OF ARTILLERY AND TANK BLAST NOISE

For the purposes of creating a manageable research design, certain idealized properties were assumed in conceiving the model for a shelter that could reduce large-gun blast noise near training ranges. Specifically, a hemispherical barrier design was used, even though such a configuration would be impractical for widespread implementation at training facilities, as the spherical surface would be very difficult and expensive to construct. It is assumed for mathematical convenience, as it is one of the few forms for which analytical solutions are known. The results are considered to be a valid guide to those expected for a more practical structure as it is known that the diffraction pattern of an obstacle is governed more by the size (as measured in wavelengths of the sound) and general proportions than by the details of the architecture.

One possible configuration for a noise-mitigating shelter is a garage-like structure partially surrounding the gun, with an orifice for the gun to fire through. For optimal effect the shelter should surround the gun as completely as possible while including an orifice of a size and angle consistent with a practical field of fire.

In simplest terms, the reduction in total radiated sound power could be calculated as the ratio of the area of the orifice to the total area of the housing, assuming that the interior surface of the shell is perfectly absorbing. Using this simplistic relationship to analyze a hemispherical structure with a semicircular orifice subtending an angle from the center of the hemisphere (Figure 1*), the reduction in radiated power could be expressed as

$$\frac{P_{\text{radiated}}}{P_{\text{source}}} = \frac{(1 - \cos \theta)}{2} \quad [\text{Eq 1}]$$

where θ = angle of the orifice in degrees.

For an orifice angle of 45 degrees, for example, the radiated power is 14.6 percent of the total power—a reduction of 8.3 dB. It is unlikely, however, that such a reduction could actually be achieved because of the idealized conditions described above.

In addition to the size and angle of the orifice, diffraction of noise around the structure is also important. In fact, most discussion and investigation of sound shelters is based on the premise that a barrier casts a sound "shadow." The immediate objective is to investigate the potential of a shelter to cast an acoustic shadow in the desired direction. This problem can be treated as one of classical diffraction theory, solved in the temporal frequency domain.

The Spectrum of a Gun Blast

A gun blast is an impulsive type of disturbance, normally described as a single-valued causal function of time. Because this diffraction problem can most directly be formulated in the temporal frequency domain, it is necessary first to determine the temporal frequency spectrum of the blast wave. The amplitude spectrum shown in Figure 2 was used in this analysis to model a large Army gun. The spectrum peaks at about 22 Hz and contains significant components as low as 5 Hz and as high as 60 Hz. To determine the behavior of a sound barrier system, the amplitude diffraction patterns can be calculated at several frequencies in this band and the squares of their moduli superimposed to produce a composite

* Figures for this chapter may be found at the end of this chapter.

power pattern. The composite power pattern is equivalent to the sound exposure level produced by the pulse, as shown by Parseval's theorem or Rayleigh's theorem.¹

The Shelter Model

Gun shelter models generally envision an enclosure with the fewest and smallest orifices possible that will permit the necessary traversing and elevating of the gun. To perform a diffraction computation without undue complication it is desirable that the boundaries of the insonified space be simply represented in some coordinate system in which the wave equation is separable and whose basis functions are well understood. For this reason the hemispherical shelter illustrated in Figure 1 is postulated, having a perfectly reflecting ground surface and an open door described by an angle subtended from the center of the sphere. According to image theory such a configuration is the equivalent of a complete sphere in unbounded space. This is not, of course, an economical or convenient structure to build or use, but experience with diffraction problems suggests that a diffraction pattern depends much less on the details of the architecture than on the physical size of the structure as measured in wavelengths. Therefore, the hemispherical "band shell" used in this model can provide a good quantitative indication of how a more conventional rectilinear structure of the same general dimensions and proportions would perform.

This spherical diffraction problem was solved for some special cases more than 100 years ago² and has been described by many authors.³ The sound source is described as an axially symmetric function of radial particle velocities at the surface of the shell; these velocities are zero everywhere except for a constant velocity u_0 from zero degrees to the azimuthal angle of the door (the dashed lines in Figure 1):

$$U(\theta) = \begin{cases} u_0, & 0 \leq \theta < \theta_0 \\ 0, & \theta_0 < \theta \leq \pi \end{cases} \quad [\text{Eq 2}]$$

This assumption of constant velocity is reasonable in absence of specific information about the velocity distribution produced by a gun, and is expected to give a good representation of the noise shielding provided by the shelter. As mentioned under "Results of the computations," the diffraction pattern is not a strong function of aperture width. This suggests that the primary sound radiation pattern of the gun is not critical to the outcome.

The surface velocity function is expanded into a series of Legendre functions:

$$U(\theta) = \sum_{m=0}^{\infty} U_m P_m(\cos \theta) \quad [\text{Eq 3}]$$

where the coefficients U_m are found from the integral

$$U_m = (m+1/2) \int_0^{\pi} U(\theta) P_m(\cos \theta) \sin \theta d\theta \quad [\text{Eq 4}]$$

¹ R. Bracewell, *The Fourier Transform and its Applications* (McGraw Hill Book Co., New York, 1965).

² Lord Rayleigh, *Theory of Sound*, Vol 2 (Dover Publications, New York, 1945).

³ P.M. Morse, *Vibration and Sound* (McGraw-Hill, 1936).

For the velocity function given by [Eq 3], this integral has the value

$$U_m = \frac{1}{2} u_0 [P_{m-1}(\cos \theta_0) - P_{m+1}(\cos \theta_0)] \quad [\text{Eq 5}]$$

The radiated pressure wave is described by the axially symmetric spherical wavefunction. This wavefunction may be separated into radial and azimuthal components, which are Hankel functions and Legendre functions, respectively, and expanded as a series of these functions:

$$p = \sum_{m=0}^{\infty} A_m P_m(\cos \theta) h_m(kr) e^{-i\omega t} \quad [\text{Eq 6}]$$

The expansion coefficients A_m are found from the U_m by utilizing the boundary condition of particle velocity at the surface of the sphere, found from the gradient of the pressure:

$$u_s = -\frac{i}{\rho \omega} \sum_{m=0}^{\infty} A_m P_m(\cos \theta) \frac{d}{dr} h_m(kr) \big|_{r=a} e^{-i\omega t} \quad [\text{Eq 7}]$$

where

$$\frac{d}{dr} h_m(kr) = \frac{k}{2m+1} [m h_{m-1}(kr) - (m+1) h_{m+1}(kr)] \quad [\text{Eq 8}]$$

Relating the surface velocity [Eq 5] and particle velocity [Eq 7] series term by term yields an expression for the expansion coefficients:

$$A_m = i \rho c U_m \frac{(2m+1)}{m h_{m-1}(ka) - (m+1) h_{m+1}(ka)} \quad [\text{Eq 9}]$$

As the source frequency increases, the pressure wave [Eq 6] must be calculated to higher orders to maintain a desired level of accuracy. The order of calculation was determined by observing the approximate order past which the results were stable. Summations involving from 25 to 1000 terms were needed, which required the careful computation of the intrinsic functions involved in the calculations. The computations were performed on a 80386-based microcomputer with a math coprocessor operating at 16 MHz; up to 6 hours were required for the broad spectrum high frequency cases. See the Appendix for the FORTRAN code used in these calculations.

The levels are plotted in decibels with respect to the pressure that would exist at the same radial distance due to an isotropic point source with power equal to the total power radiated through the opening of the shelter. This reference pressure may be found by integrating the intensity over the surface of the opening or, equivalently, integrating intensity over the entire hemisphere at some radius.

Results of the Computations

Figures 3 through 7 give the level of the diffracted sound field at a distance of 2 km from a source sheltered by a hemispherical shell 10 m in radius with an opening subtending 45 degrees in height from the center of the sphere. This semicircular opening is 7 m high and 14 m wide. The reference intensity is calculated as the average of the intensity in all directions; this is equal to the intensity that would be produced at 2 km by an isotropic source radiating the same total power as passes through the opening in the sphere. No assumptions are made about the characteristics of the gun other than that it produces a constant radial particle velocity over the spherical cap shown as a dashed curve in Figure 1. The diffracted field for each of five frequencies is plotted in decibels above and below the reference sound level as a function of horizontal azimuth measured from the forward (downrange) direction.

It is immediately obvious, as expected, that the shelter produces a more pronounced effect at higher frequencies than at lower ones. For example, Figure 3 indicates that the reduction in level at 10 Hz is about 5.4 dB at 130 degrees, and only about 1 dB at 180 degrees (rearward); at 50 Hz (Figure 7), however, the greatest reduction in level is 20 dB (at 166 degrees), with a reduction of about 6 dB rearward. Note that in every case there is a localized maximum in intensity at the rearward direction, as would be expected from the symmetry of the shelter's geometry. This is the "Poisson's bright spot" phenomenon well known from optics.⁴

It is fruitless to try to predict phase propagation effects over substantial distances. The obvious approach is to superimpose the intensities⁵ at all frequencies, each numerically weighted in accordance with Figure 2.

The results of this analysis are illustrated in Figures 8 through 10. The results are not encouraging to the goal of sheltering rearward areas from gun blast noise. Figure 8 shows that the 10 m radius shelter gives a maximum of 10.3 dB protection at 150 degrees, and only about 4.5 dB at 180 degrees. Figure 9 shows the effects of altering the door opening. It is obvious that increasing the door opening to 90 degrees impairs the shelter's rearward noise attenuation properties, providing a maximum protection of 8.5 dB at 147 degrees, and 1.3 dB rearward. A 60 degree opening provides about 1 dB less overall protection than the 45 degree case. Doubling the radius of the shelter to 20 m produces an improvement of about 3 dB (Figure 10), not a significant one in terms of human perception. Furthermore, this modest improvement comes at great cost in terms of structure size. Reducing the radius to 5 m impairs the shelter's overall performance by about 3 dB.

Noise Mitigation Potential

As demonstrated here through the application of diffraction theory, the use of a garage-like enclosure at the firing point to shelter rearward areas from large guns (i.e., artillery and tank blast noise) does not appear to promise much practical benefit. The substantial low frequency (long wavelength) content of a large gun's sound power spectrum implies that any structure theoretically capable of significant shadowing rearward would be much too large to be practical. The largest structure considered in this analysis—the hemispherical shell 20 m in radius analyzed in Figure 10—produces a rearward level reduction of only about 6.3 dB, and a maximum reduction of 14 dB at 154 degrees. A suitable structure of this size, even if of a more conventional, rectilinear shape, would undoubtedly be very costly. The structure would have to be strong enough to withstand the stress of repeated blast-induced vibrations and could require expensive interior acoustical treatment to protect the hearing of gunners. It would also increase noise levels downrange to the same degree that it decreases them rearward.

⁴ R. Guenther, *Modern Optics* (John Wiley and Sons, New York, 1990); M. Born and E. Wolf, *Principles of Optics*, 6th Edition (Pergamon Press, Oxford, 1989).

⁵ At 2 km from the source the wavefront can be considered to be planar, so intensity is essentially proportional to pressure squared.

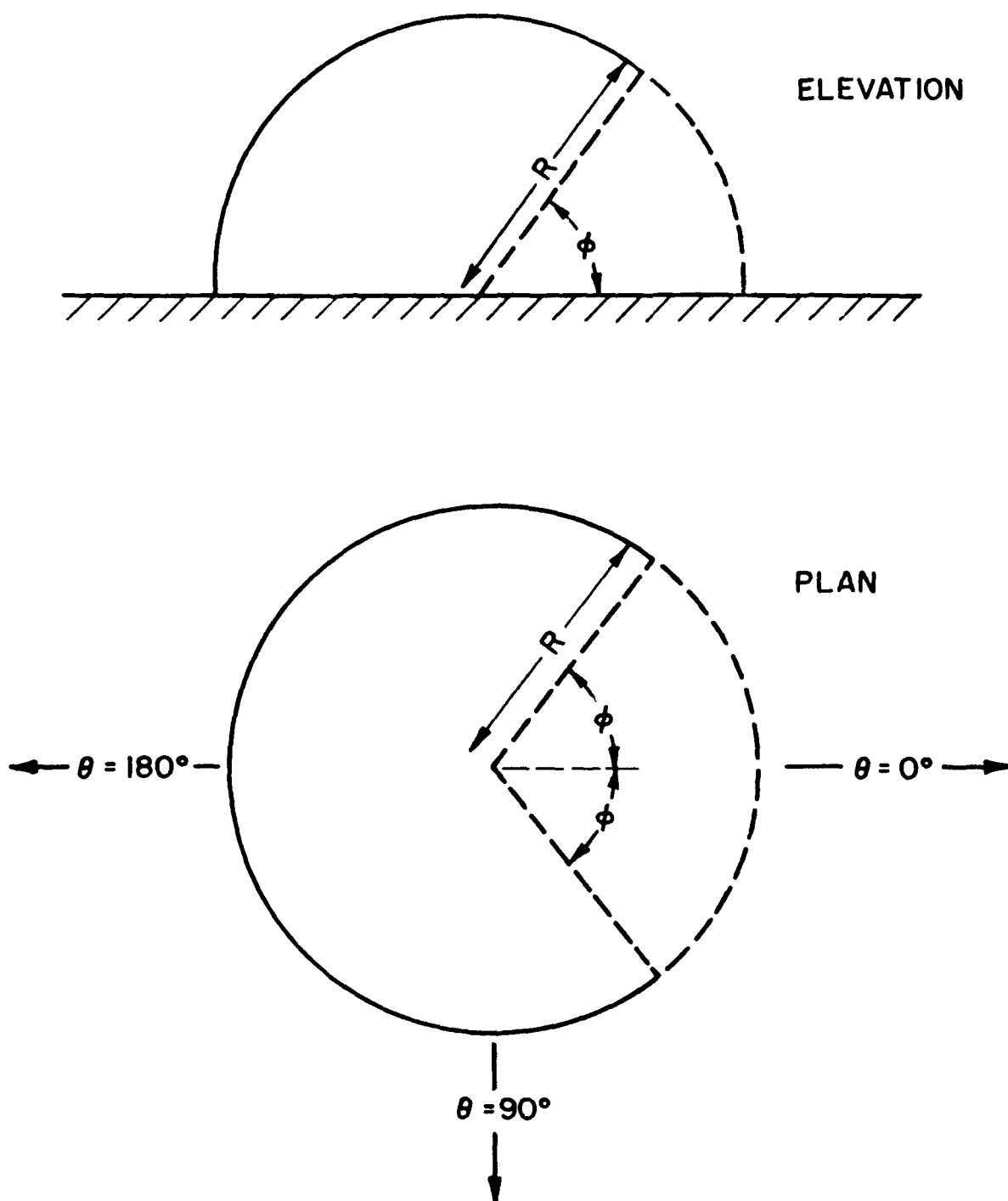


Figure 1. Plan and elevation diagrams of a spherical acoustic shelter for a large gun.

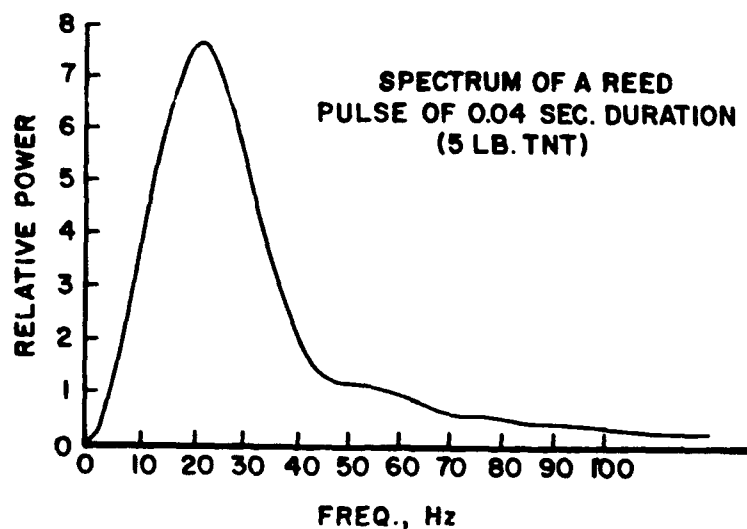
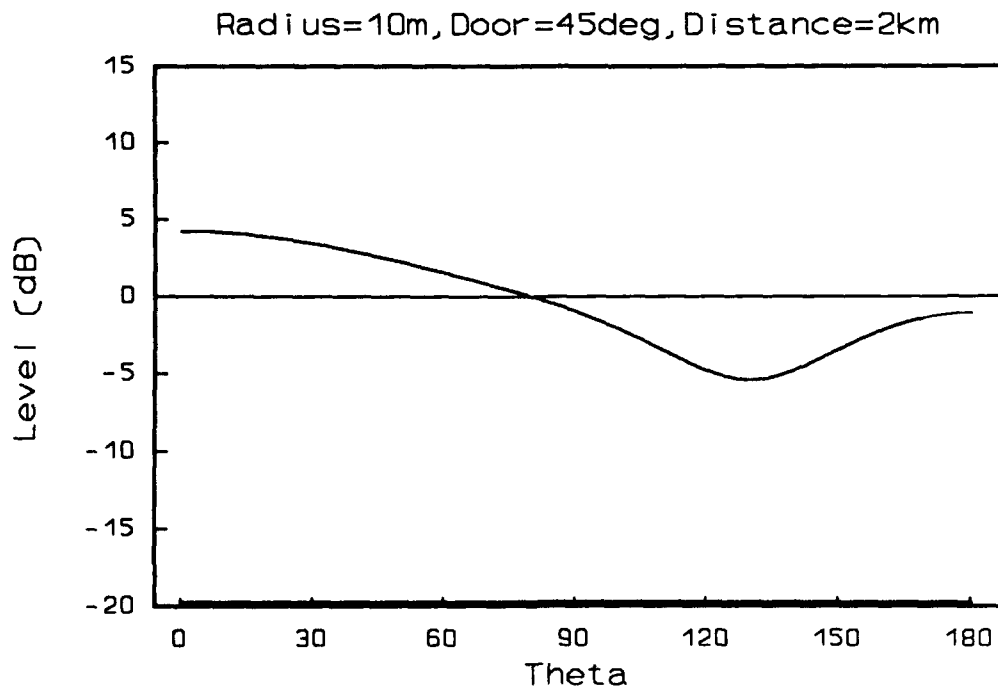
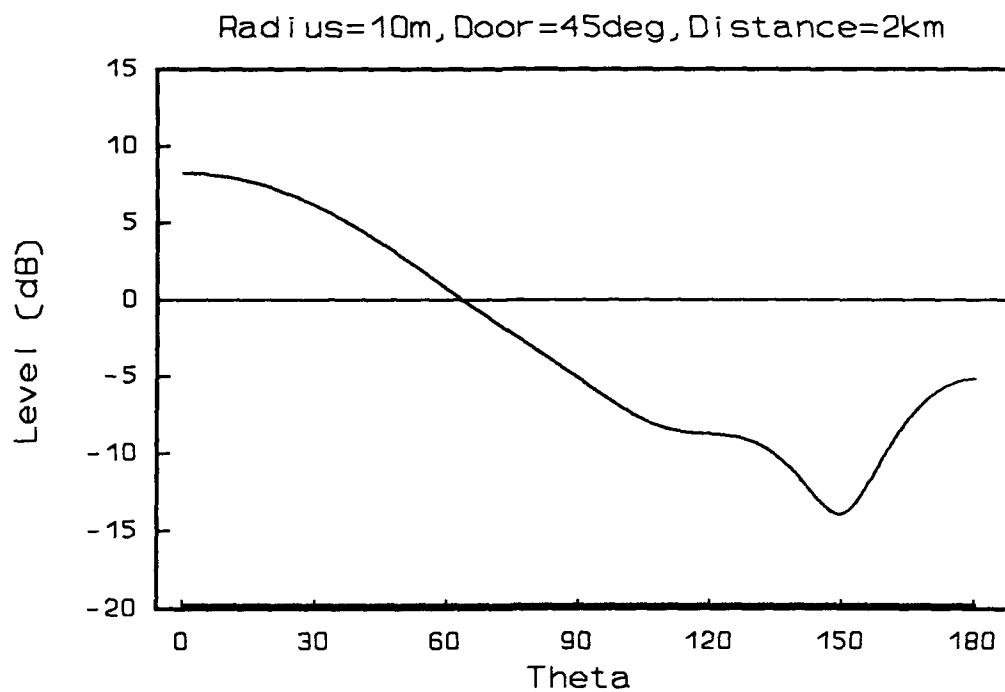


Figure 2. Assumed spectrum of a large caliber gun pulse.



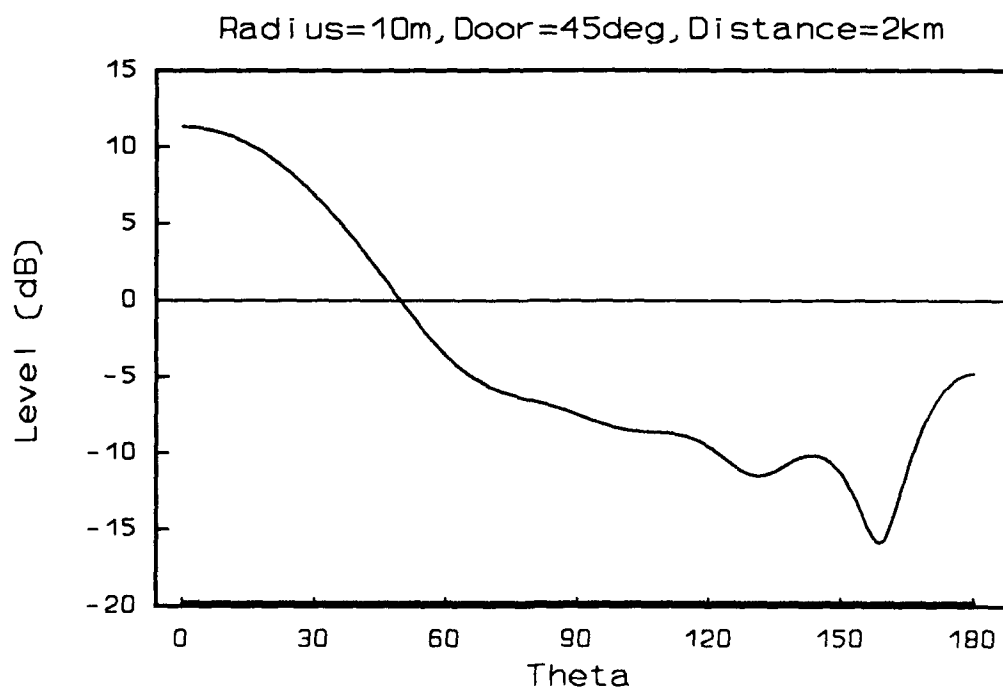
Calculation to 25th order.

Figure 3. Diffraction pattern cast by shelter at 10 Hz.



Calculation to 25th order.

Figure 4. Diffraction pattern cast by shelter at 20 Hz.



Calculation to 30th order

Figure 5. Diffraction pattern cast by shelter at 30 Hz.

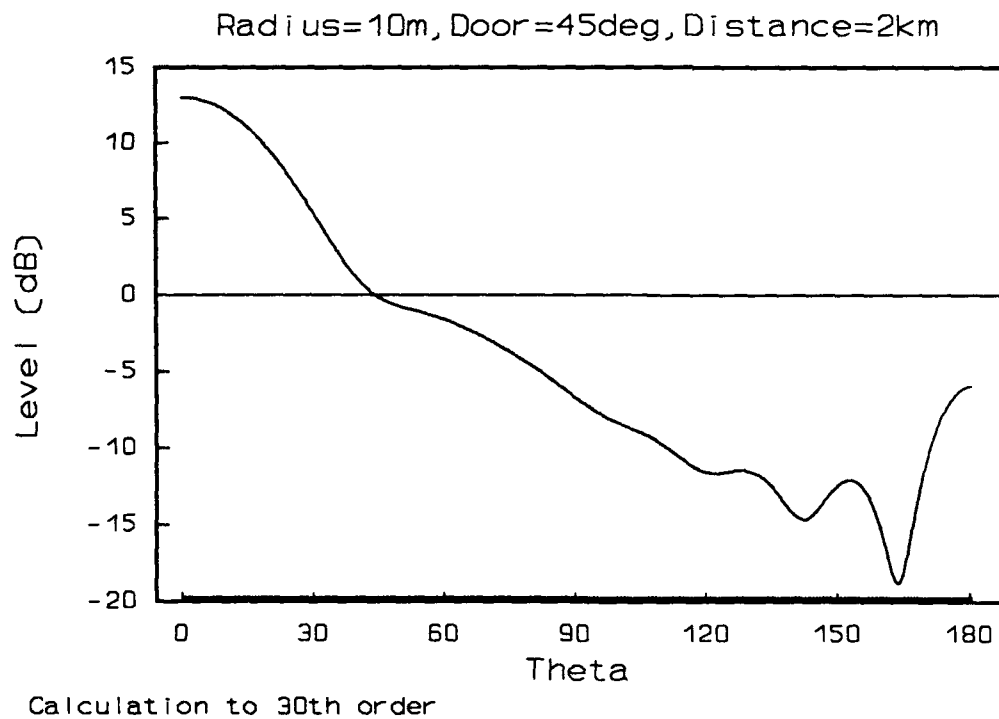


Figure 6. Diffraction pattern cast by shelter at 40 Hz.

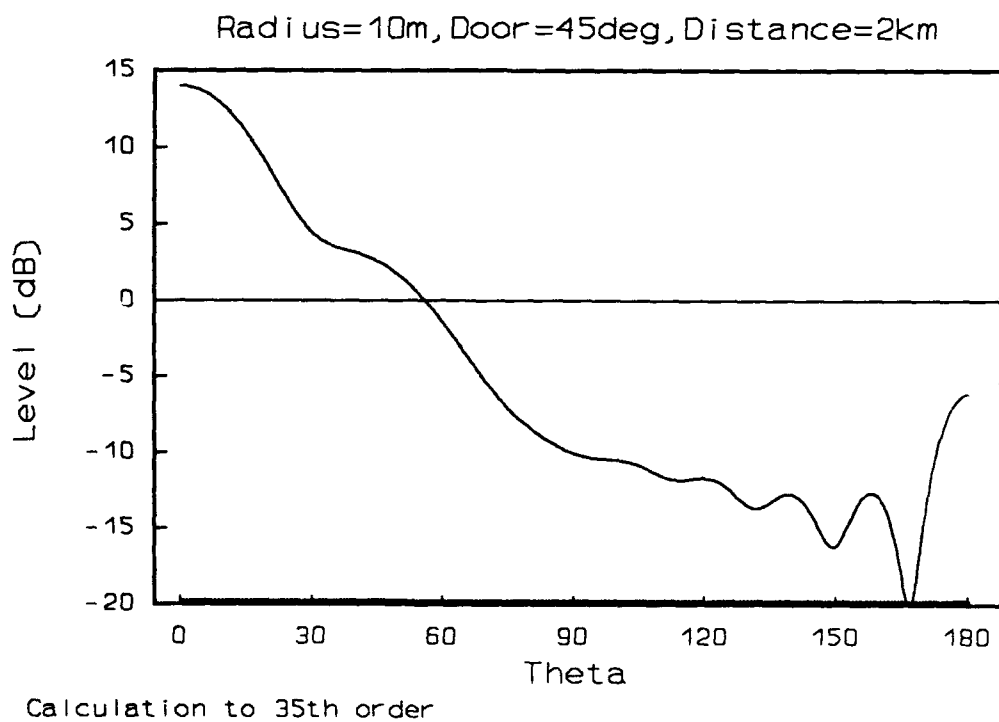


Figure 7. Diffraction pattern cast by shelter at 50 Hz.

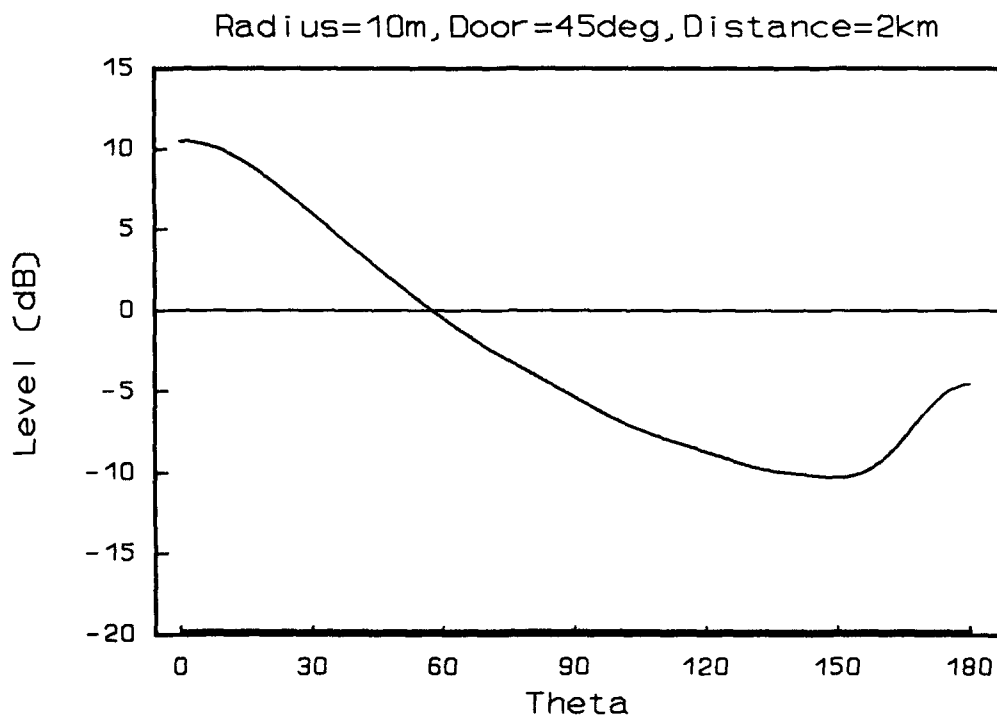


Figure 8. Composite diffraction pattern for five frequencies weighted according to Figure 2.

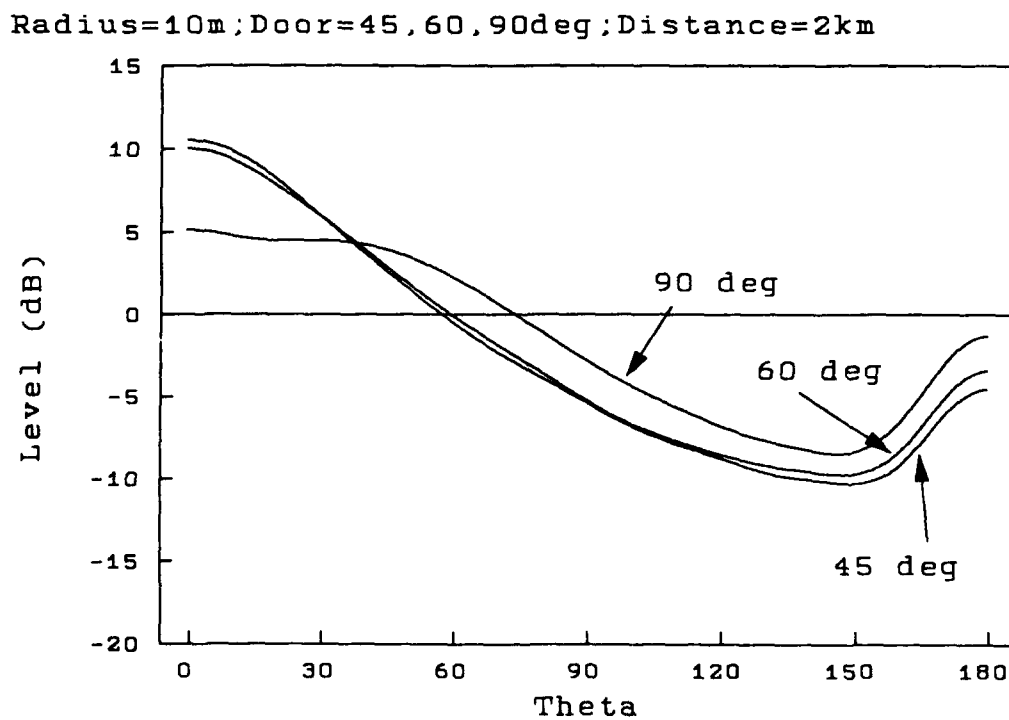


Figure 9. Composite diffraction cast by alternate aperture angles.

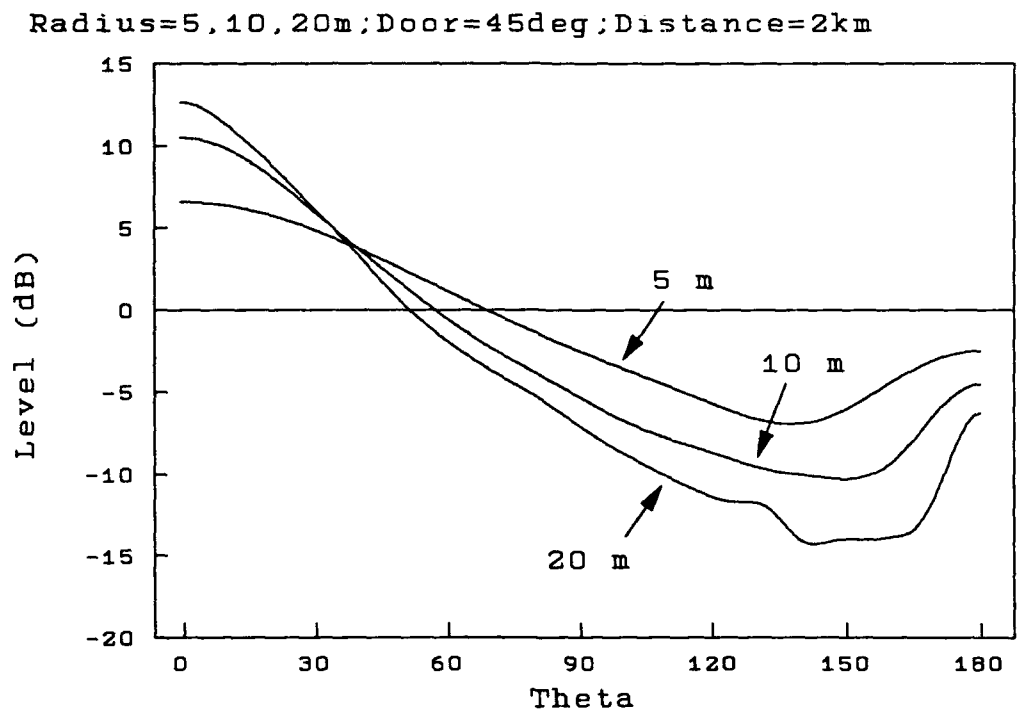


Figure 10. Composite diffraction pattern cast by alternate shelter radii.

3 SHELTERING THE SOURCE OF RIFLE FIRE NOISE

As in Chapter 2, several assumptions were made to facilitate analysis of the diffraction of rifle fire noise by a semi-open structure. The computations follow the method given in Chapter 2.

An open-sided shed 7 m high and 14 m wide was modeled by a quarter-sphere, as shown in Figure 11. While the configuration of the shelter in Chapter 2 (Figure 1) was designed to use the smallest possible aperture that would permit a practical field of large-gun fire, the shelter in Figure 11 was configured to simulate an existing shed with which the authors are familiar. This shed is more open than the shelter modeled in Figure 1, and this is reflected in its configuration. The actual shed is a rectilinear structure, but this kind of diffraction problem cannot be solved analytically for such a structure. The justification for using a spherical form in this analysis is the same as in the earlier one: the principal determinant of the overall diffraction pattern is the barrier's dimensions as measured in wavelengths, not the details of the geometry. In terms of diffraction effects, a spherical shell is believed to be a good model for a rectilinear shed of similar dimensions.

The frequency spectrum of the gunshot is assumed to be as shown in Figure 12. Rifle fire within the structure is assumed to produce a field of uniform amplitude and phase over the spherical boundaries indicated by the dashed line in Figure 11. This assumption expedites the mathematical analysis, but it is questionable in comparison to a real-world setting. However, in the absence of real data it is as reasonable an assumption as any other. If and when directional data become available for the type of weapon considered here, the performance of the shed can be reevaluated.

The outside of the shed is assumed to be acoustically hard and the interior is completely absorbing. Very high absorption coefficients can be obtained in the frequency range considered, so the assumption of complete absorption within the shell is realistic. (Note, however, that the assumption of interior absorption is immaterial to this analysis, which is based on the total power radiated from the shelter).

Results of the Analysis

Figures 13, 14, and 15 give the diffraction patterns at 250, 500, and 1000 Hz respectively for the shelter represented in Figure 11. The angle θ is 0 degrees in the forward (downrange) direction and 180 degrees rearward. Figure 16 is the sum of diffraction patterns for 63 Hz to 8000 Hz (third octaves) weighted according to Figure 12. The A-weighted spectrum is shown to account for the response of the human ear; as expected, the A-weighted spectrum resulted in greater overall protection, as the lower frequencies are attenuated. The sound pressure levels are plotted in decibels with respect to "isotropic" where the isotropic level is what one would expect if all the energy radiated through the dashed boundaries in Figure 11 were radiated from an isotropic point source. For a given source at the center of the sphere the radiated field should be as given in Figure 16 (see previous paragraph) minus about 3 dB to account for absorption by the inside of the shelter.

The results of the analysis indicate that, owing solely to diffraction by this shelter, the reduction in sound pressure at 180 degrees (rearward) is 0.3 dB. However, the curve is quite steep in this region, and at 175 degrees, the reduction is about 11.3 dB for the unweighted spectrum, and 15.7 dB with the A-weighting. The maximum reduction is 18 dB for the unweighted spectrum and 21.7 dB with A-weighting, each at 150 degrees. At 90 degrees there is a reduction of 3.2 dB for both curves, and at 0 degrees—directly downrange—there is a gain of 4.8 dB for each.

Noise Mitigation Potential

The results indicate that a shelter of the approximate dimensions and proportions of those assumed for the structure in this analysis should substantially reduce rifle noise radiated at angles greater than 90 degrees from straight downrange. The very sharp peak in intensity in the rearward direction is a result of the idealized model assumed here. This phenomenon would be experienced to some extent in any such structure and should be considered in siting the structure.

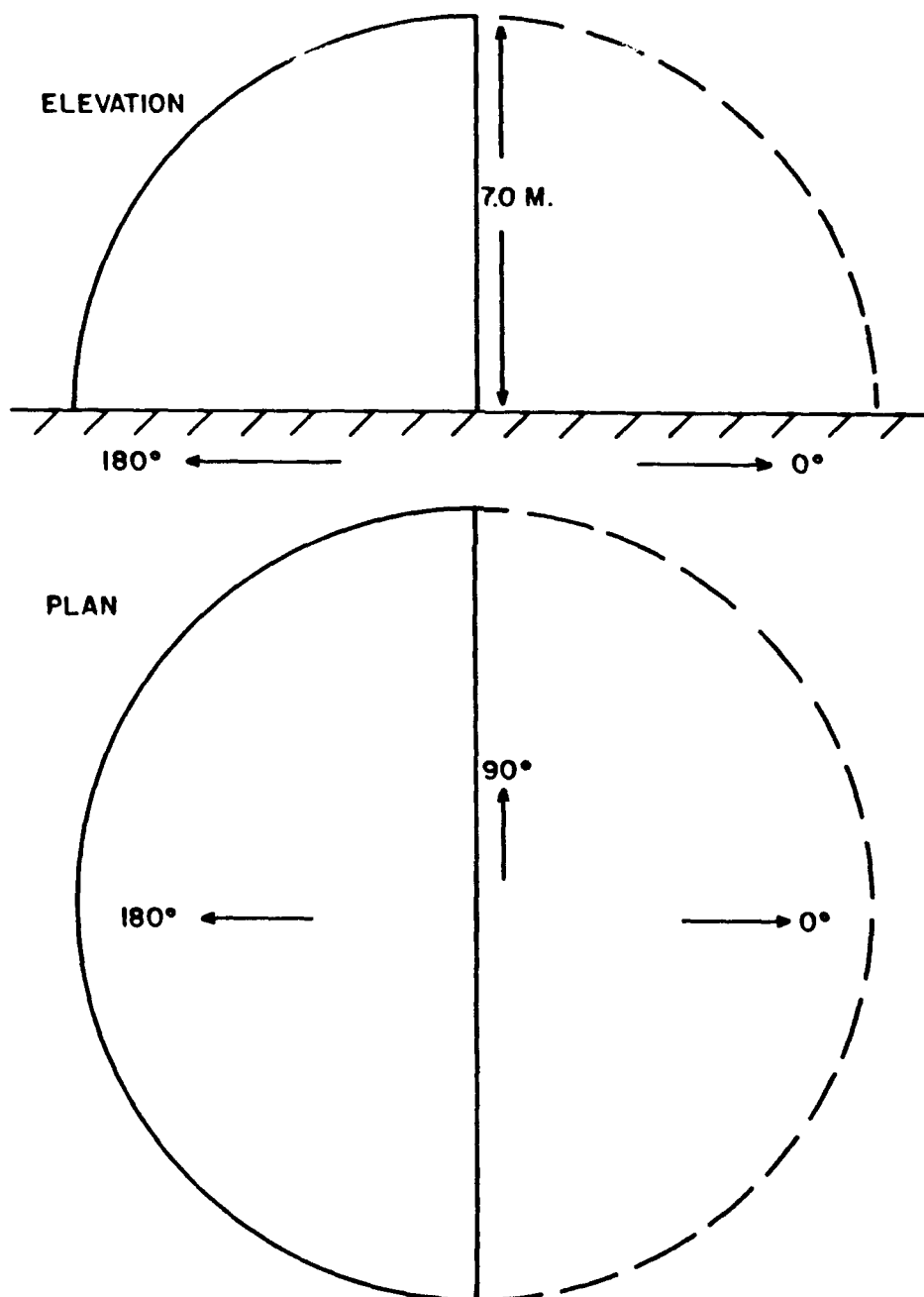


Figure 11. Plan and elevation diagrams of a spherical acoustic shelter for rifle fire noise.

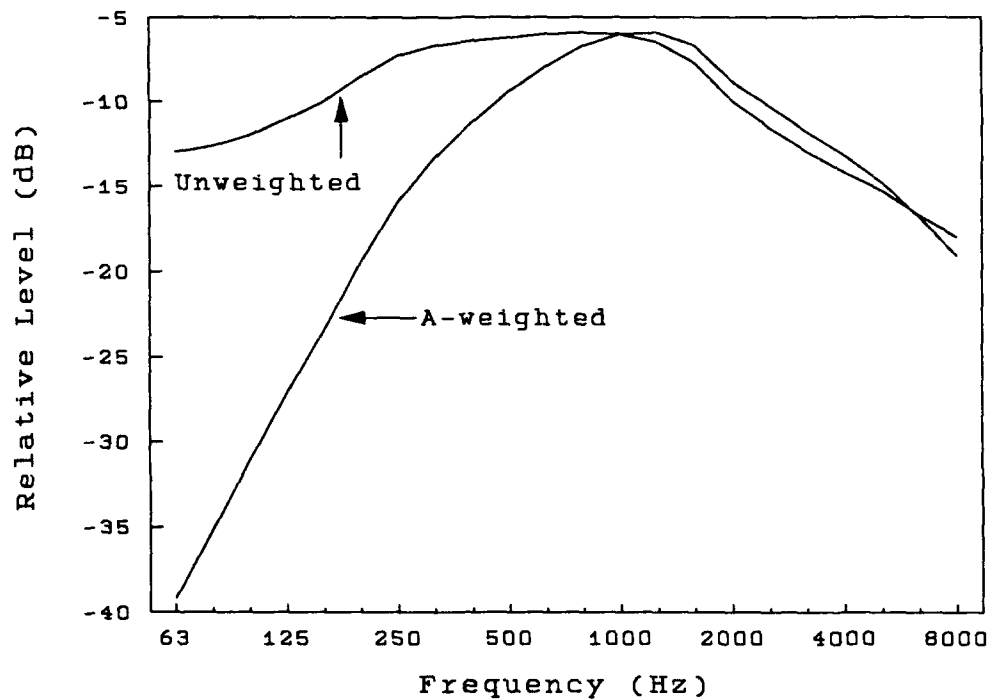


Figure 12. Assumed spectrum of a small caliber arms pulse.

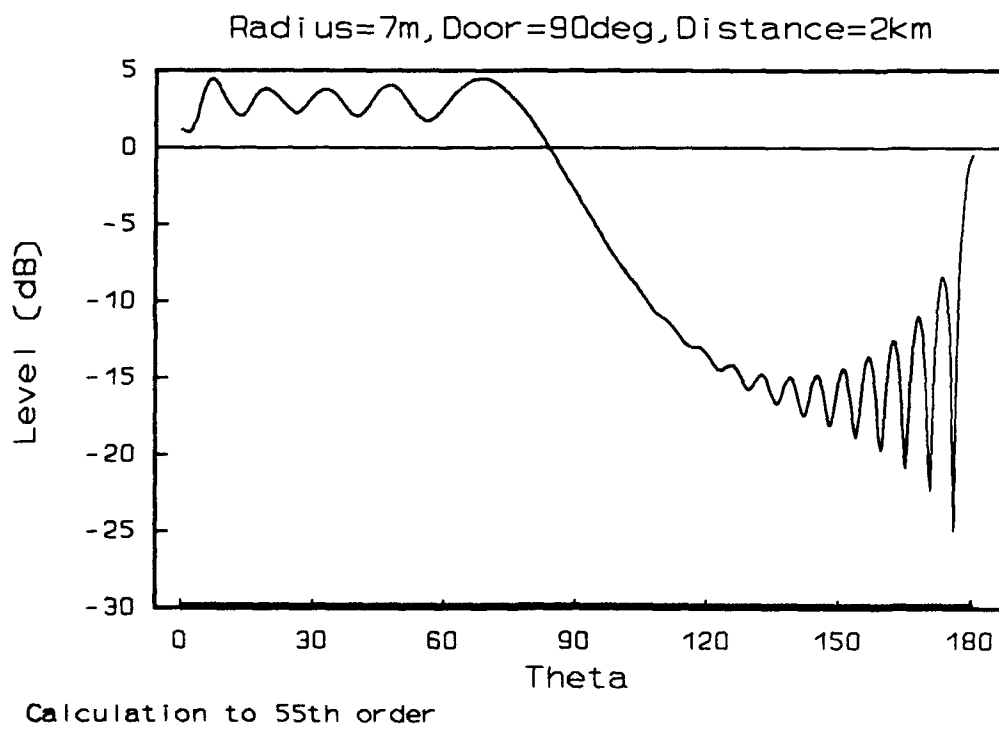
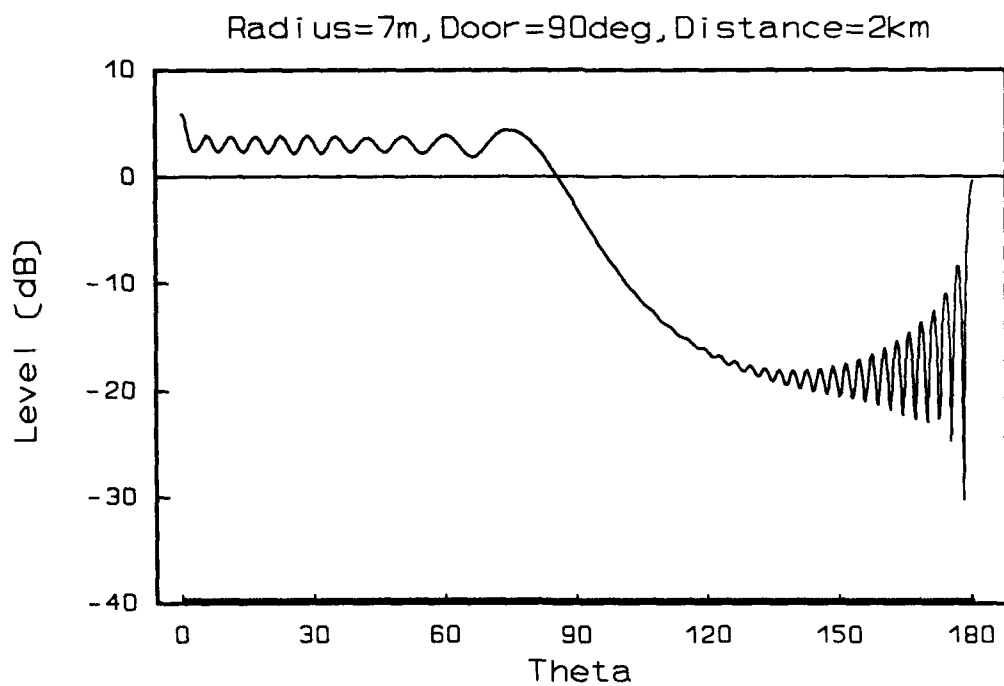
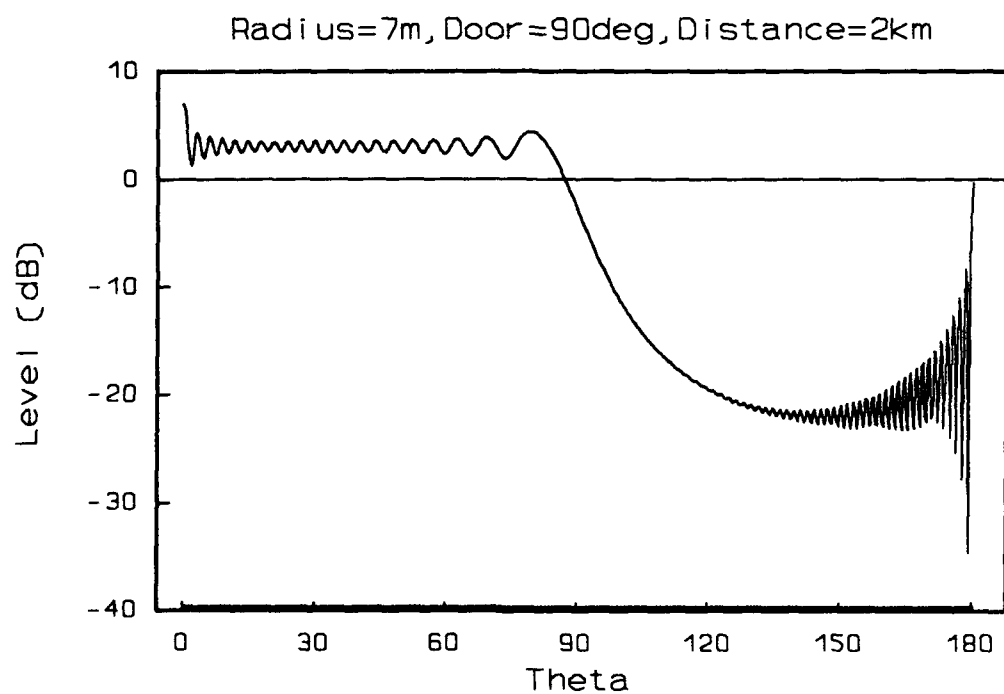


Figure 13. Diffraction pattern cast by shelter at 250 Hz.



Calculation to 85th order.

Figure 14. Diffraction pattern cast by shelter at 500 Hz.



Calculation to 150th order

Figure 15. Diffraction pattern cast by shelter at 1000 Hz.

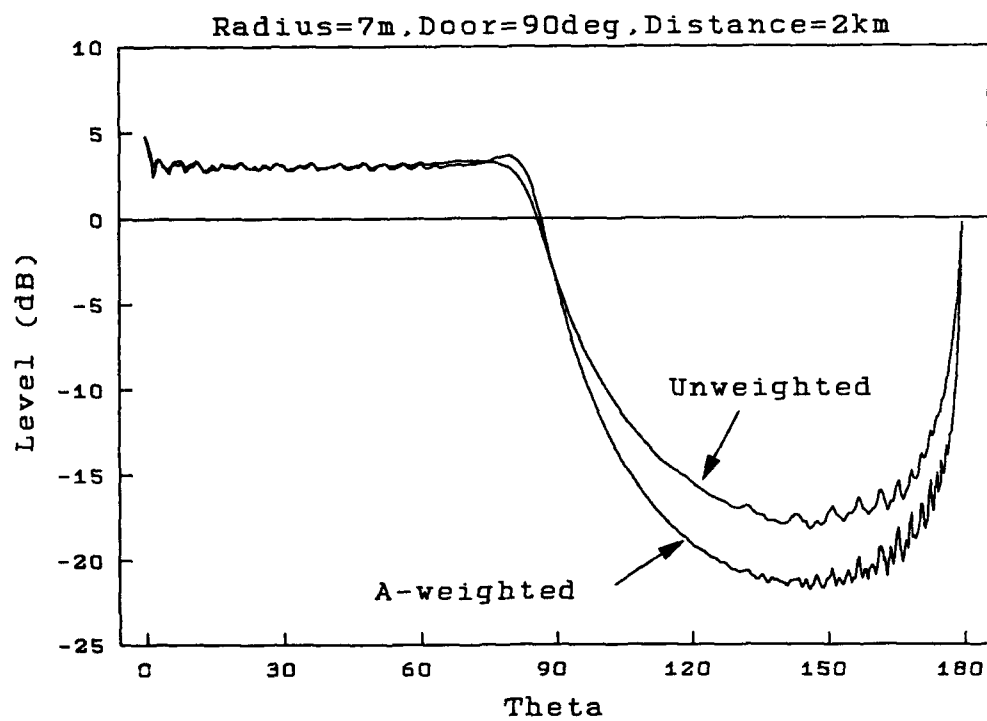


Figure 16. Composite diffraction pattern due to rifle noise, 63 Hz to 8000 Hz, third octaves.

4 CONCLUSIONS

Mathematical analyses of the noise-mitigation potential of idealized band-shell-type structures documented in this report lead to the following conclusions:

1. The use of a garage-like enclosure at the firing point of artillery or tanks to shelter rearward areas from training range blast noise does not appear to promise any practical benefit. The substantial low frequency (long wavelength) content of a large gun's sound power spectrum implies that any structure theoretically capable of significant acoustical shadowing rearward would be much too large to be practical.

2. The use of a semi-open shed at the firing point of a rifle to shelter rearward areas from muzzle noise should provide substantial noise-reduction benefits. Owing solely to diffraction by the shelter, the reduction in sound pressure at 180 degrees (rearward) is 0.3 dB. At 100 degrees there is a reduction of 9.3 dB using the unweighted spectrum and 11.5 with A-weighting, and at 0 degrees—directly downrange—there is a gain of 4.8 dB (Figure 16). After accounting for the noise-absorption properties of the interior of the shelter, another drop of roughly 3 dB could be expected across the given noise spectrum between 63 and 8000 Hz. This indicates that a shelter of the approximate dimensions and proportions modeled should substantially reduce rifle noise radiated at angles greater than 90 degrees from straight downrange.

APPENDIX: FORTRAN CODE USED IN THE CALCULATIONS

```

C   PROGRAM house5.6
C-----
C       Calculates the sound field outside
C       a spherical house with the source inside.
C       The outside wall is rigid.
C       Sufficient expansion order of harmonic function
C       depends on frequency and geometry, up to 2000 accepted.
C       Accepts up to 25 weighted frequency components.
C-----
C
C       VARIABLES
C       A=house radius
C       TH0=door aperture angle in degrees
C       TH=observer angle
C       F(25)=array of 25 frequency bands, in Hz
C       WT(25)=array of dB weightings for each band
C       U0=velocity of air at door in m/s
C       R=radial distance to observer, in meters
C       MORDER(I)=expansion order of harmonic f'n for band #I
C       C=sound velocity, m/s
C       PREF(I)=reference (isotropic) sound pressure for band #I
C       SP2,SPR2=squared sums of diffracted and reference pressures
C       HANA,HANR=arrays of Hankel functions with arguments ka & kr
C       LEG=array of Legendre functions
C-----

      COMPLEX*8 AM,HM,P,PP(25,512),CUM,HANA(-1:2000),
1      HANR(-1:2000)
      REAL*4 PREF2(25),F(25),WT(25),SP2,SPR2,LEG(-1:2000)
      INTEGER MORDER(25)

      OPEN(20,file='th.d')
      OPEN(21,file='db.d')

      WRITE(6,*)'Welcome to HOUSE 5.6!'
      WRITE(6,*)'Enter the radius of the sphere, in meters:'
      READ(*,*)A
      WRITE(6,*)'Enter the door aperture angle, in degrees:'
      READ(*,*)TH0
      WRITE(6,*)'How many frequency bands? (Max 25)'
      READ(*,*)BANDS

      DO 10 I=1,BANDS
        WRITE(6,*)'Enter the frequency (Hz) of band #',I,':'
        READ(*,*)F(I)
        WRITE(6,*)'Enter the attenuation (dB) for the',
1        INT(F(I)), ' Hz band:'
        READ(*,*)WT(I)
        WRITE(6,*)'Enter harmonic order for this band. (Max 2000)'
        READ(*,*)MORDER(I)
10    CONTINUE

      WRITE(6,*)'Enter the air velocity at the door in m/s:'
      READ(*,*)U0
      WRITE(6,*)'Enter the distance of observer from house, in meters:'
      READ(*,*)R

C-----Set constants for pi, speed of sound, density

      PI=3.1415927
      C=340.
      RHO=1.2928
      TH0=TH0*PI/180.
      CTH0=COS(TH0)

```


C-----F(IFF) is the frequency of band #IFF (1-5)

```
DO 515 IFF=1,BANDS
  WRITE(6,*)F(IFF),'Hz'
  W=2.*PI*F(IFF)
```

C-----W is the angular frequency of the band
C-----VKA is ka,VKR is kr

```
VK=W/C
VKA=VK*A
VKR=VK*R
```

C-----Create Hankel Function tables

```
CALL SHAN(MORDER(IFF)+1,VKA,HANA)
CALL SHAN(MORDER(IFF)+1,VKR,HANR)
```

C-----Create Legendre Function tables

```
CALL LEGT(MORDER(IFF)+1,CTH0,LEG)
```

C-----Go through all angles 0 -> pi

```
WRITE(6,*)
DO 101 I=1,512
  DTH=PI/511
  TH=(I-1)*DTH
  CTH=COS(TH)
  P=0.
  TEMPTH=TH*180/PI
  WRITE(6,15)TEMPTH
15  FORMAT('Angle: ',F5.1)
```

C-----Sum to MORDER for present band

```
DO 102 J=0,MORDER(IFF)
  M=J
```

C-----Calculate CUM=Um, the coefficients in the Legendre expansion

```
SLP=LEG(M+1)
SLM=LEG(M-1)
CUM=CMPLX(0.5*U0*(SLM-SLP),0.)
```

C-----Calculate AM=Am, expansion coefficients for the pressure wave

```
AM=CMPLX(0.,RHO*C*(2.*M+1.))*CUM
AM=AM/(CMPLX(M,0.)*HANA(M-1)-CMPLX(M+1.,0.)*HANA(M+1))
```

C-----Add this order harmonic to the pressure wave.

```
CALL SLEG(M,CTH,PM)
HM=HANR(M)
P=P+AM*CMPLX(PM,0.)*HM

102  CONTINUE
  THDEG=TH*180/PI
  PP(IFF,I)=P
101  CONTINUE
515  CONTINUE
```

C-----Compute PREF2=Ref. pressure² : isotropic, same power, no shell

C-----Integral of intensity over hemisphere at radius R

```
WRITE(6,*)'Computing Pref'
DTH=PI/511
DO 701 I=1,BANDS
  PREF2(I)=0.0
DC 702 J=1,512
  TH=(J-1)*DTH
  PREF2(I)=PREF2(I)+ABS(PP(I,J))**2*SIN(TH)
```

```

702 CONTINUE
  PREF2(I)=PREF2(I)*DTH/2
  WRITE(6,*)'Pref^2,weight==',PREF2(I),WT(I)
701 CONTINUE

```

C-----Compute total level, from weighted sum of intensities

```

  WRITE(6,*)'Summing intensities for all bands'
  DTH=PI/511
  DO 505 I=1,512
    TH=(I-1)*DTH
    X=TH*180./PI
    DB=0.0

```

C-----Find weighted sum of pressures of bands (J) at angle (I)

```

  SP2=0.
  DO 535 J=1,BANDS
    SP2=SP2+(10**((WT(J)/10))*(ABS(PP(J,I)))**2
535 CONTINUE

```

C-----Find weighted sum of all Pref's of bands (J) at angle (I)

```

  SPR2=0.
  DO 545 J=1,BANDS
    SPR2=SPR2+(10**((WT(J)/10))*PREF2(J)
545 CONTINUE

```

C-----DB is the final level calculation

```

  DB=10.*LOG10(SP2/SPR2)
  WRITE(20,*)X
  WRITE(21,*)DB
505 CONTINUE
  STOP
  END

```

C-----Legendre table Subroutine

C-----Returns array leg(m)=P

```

  SUBROUTINE LEGT(M,X,P)
  INTEGER M
  REAL*4 X,P(-1:100.)

  PMM=1.
  P(-1)=1.
  P(0)=1.
  P(1)=X
  PMMP1=X

  DO 101 I=2,M
    PLL=(X*(2*I-1)*PMMP1-(I-1)*PMM)/I
    PMM=PMMP1
    PMMP1=PLL
    P(I)=PLL
101 CONTINUE

  RETURN
  END

```

C-----Legendre Polynomial Subroutine

C-----Returns Pm(x)=P

```

  SUBROUTINE SLEG(M,X,P)
  INTEGER M
  REAL*4 X,P

```

```

PMM=1.
IF (M.LE.0) THEN
  P=PMM
ELSE
  PMMP1=X
  IF (M.EQ.1) THEN
    P=PMMP1
  ELSE
    DO 101 I=2,M
      PLL=(X*(2*I-1)*PMMP1-(I-1)*PMM)/I
      PMM=PMMP1
      PMMP1=PLL
101  CONTINUE
    P=PLL
  ENDIF
ENDIF
RETURN
END

```

C-----Hankel Subroutine

C-----Returns Hm(x)=H

```

SUBROUTINE SHAN(M,X,H)
COMPLEX*8 H(-1:2000),HH1,HH0
INTEGER M
REAL X
REAL*8 BJ,BJP,BJM,BY,BYP,BYM,SUM
PARAMETER(IACC=40,BIGNO=1.E10,BIGNI=1.E-10)

```

C-----Compute Ho(x) and H1(x)

```

HH0=CMPLX(SIN(X)/X,-COS(X)/X)
H(0)=HH0
HH1=CMPLX(-COS(X)/X,-SIN(X)/X)*CMPLX(1.,1./X)
H(1)=HH1
IF (M.EQ.1) GO TO 999

```

C-----Recursion loop for real part of Hm (bessel f'n)

C-----From 'Numerical Recipes' William Press et. al.

```

IF(X.GT.FLOAT(M))THEN
  BJM=REAL(HH0)
  H(0)=CMPLX(BJM,0.)
  BJ=REAL(HH1)
  H(1)=CMPLX(BJ,0.)
  DO 100 J=1,M-1
    BJP=(2.*J+1.)/X*BJ-BJM
    BJM=BJ
    BJ=BJP
    H(J+1)=CMPLX(BJ,0.)
100  CONTINUE
ELSE

```

C-----Backwards Recurrence from arbitrary values, then normalize.

C-----Forwards Recurrence pollutes values for orders higher than argument

```

SUM=0.
BJP=0.
BJ=1.
DO 200 J=M+200,1,-1
  BJM=(2.*J+1.)/X*BJ-BJP
  BJP=BJ
  BJ=BJM
  IF(ABS(BJ).GT.BIGNO)THEN
    BJ=BJ*BIGNI
    BJP=BJP*BIGNI
    H=H*CMPLX(BIGNI,0.)
    SUM=SUM*BIGNI*BIGNI
  ENDIF
  SUM=SUM+(2*(J-1)+1)*BJ*BJ
  IF(J.LE.M+1)H(J-1)=CMPLX(BJ,0.)
200

```

```

200  CONTINUE
      H=H/CMPLX(SQRT(SUM),0.)
      ENDIF

C-----Compute imaginary part of Hm (Neumann f'n)

      BY=IMAG(HH1)
      H(1)=H(1)+CMPLX(0.,BY)
      BYM=IMAG(HH0)
      H(0)=H(0)+CMPLX(0.,BYM)
      DO 150 J=1,M-1
        BYP=(2.*J+1)/X*BY-BYM
        BYM=BY
        BY=BYP
        H(J+1)=H(J+1)+CMPLX(0.,BY)
150  CONTINUE

C-----Find M=-1 term

999  H(-1)=H(0)*CMPLX(0.,1)
      RETURN
      END

```

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